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Fast Aerodynamic Simulation for Military Procurement

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Abstract

Numerical simulation of airborne vehicle performance is of increasing importance to military. Such simulations become integral to procurement strategy when they can provide fast answers to performance related inquiries. Except for being able to identify the more challenging real time turbulence scales and other grid dependent issues related to complex configuration studies, the computational methods have matured to a stage where they are bringing virtues of different disciplines together, to couple efficiently for the best possible design. Increasing computational power has provided modelers the ability to seek more knowledge per design cycle and to increase the actual number of cycles. This article discusses some of the defence related projects in which IAR has used simulation techniques to provide timely answers to such questions as the performance of advanced missile systems, prediction of trajectories of stores released from rotor based and fixed wing aircraft and the use of optimization techniques for aircraft performance. The paper also emphasizes that for most standard performance studies, one may be able to use lower order computational methods to reach satisfactory conclusions.

Keywords: MDO, CF18 store release, Helicopter flow analysis, Missiles, Neural Network

Nomenclature

AR	Aspect ratio
C_f	Skin friction coefficient
D	Drag
ESF	Engine scale factor
h	Altitude
L	Lift
L/D	Lift-to-Drag ratio
M	Mach number
R	Range
SFC	Specific fuel factor
S_{ref}	Wing surface area
T	Throttle
t/c	Thickness/chord
W_E	Engine weight
W_F	Fuel weight
W_T	Total weight
x	Wing box cross section
xs	Horizontal displacement
zs	Vertical displacement

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t	time (second)
Λ	Wing sweep angle
λ	Taper ratio
Θ	Wing twist

Introduction

CFD based simulation is beginning to play a very important role in military acquisition of hardware. The old and tried methods of using quick empirical formulation for preliminary estimates are still useful, but the availability of cheaper computer power means that one can, at least in the initial phase, resort to lower order computational tools to obtain better information regarding the performance of the vehicle. These methods provide fast answers to most of the steady state problems encountered under normal operational conditions. Under demanding maneuvers, it is accepted that the lower order computational methods may not be able to meet the complexity of the simulation challenge. For more critical performance regimes one may have to resort to more time consuming rigorous methods to provide the answers. Advances in multi-disciplinary optimization have also provided access to powerful tools for implementing extensive searches of performance parameters across disciplines to obtain optimal combination of characteristics available.

The paper outlines the methods adopted at IAR for conducting simulation studies of military aerospace vehicles to examine their attributes and capabilities both for procurement and in- service performance under a variety of deployment situations. These numerical simulations may range from direct understanding of vehicle performance under standard flight envelope conditions to studies of stores and non-conventional mission kits attached to, and released from airborne military vehicles. For the new procurements, as indeed for the case of the Maritime Helicopter, the Department of National Defence may authorize advanced studies of vehicle performance for a better understanding of the expected service from the anticipated purchase. Very often, the numerical methods of different orders of accuracy as well as optimization techniques may be utilized in conjunction with the wind tunnel measurements to obtain quick and economically efficient answers to some of the more urgent questions.

The Simulation Methods and Discussion

Procurement of fixed wing or rotor-based aircraft, for example, has to go through a very orderly sequence of milestones. In the first stage, it is appropriate to prepare a list of performance requirements expected from the new procurement. The second step would be to identify a short list of the potential contenders, which satisfy all or many of the requirements. Multidisciplinary design optimization (MDO) techniques are advanced at the present time to provide information on the best performance configurations during the program definition phase. Recently, IAR carried out an instructive exercise using the advanced decomposition MDO algorithms, the Bi-Level Integrated System Synthesis (BLISS) [1], the Concurrent Sub-Space Optimization (CSSO) [2] and the Collaborative Optimization (CO) [3] methods to achieve at an optimized configuration designed for a supersonic performance.

The first phase in this procedure is to identify potential configurations in the market, which agree best with this configuration. For an easy management in design, these three methods decompose the complex system design into several subsystems along the line of different expertise, such as the structure, aerodynamics, propulsion and performance in an aircraft design optimization. These subsystems are able to perform optimizations concurrently and then the system gathers information from the subsystems to optimize the maximum range. The coupling information is exchanged between the subsystems and the system through the proper definitions of the objective functions and the constraints (CO), the simulation models (CSSO), and the sensitivity analysis (BLISS). For example, Figure 1 describes the typical steps needed in the BLISS optimization procedure. Table 1 is the optimization results for a supersonic jet design performed by the three methods. The analysis in each subsystem used empirical functions at the current stage. In future studies it

would be appropriate to use more advanced specific CFD techniques to simulate the characteristics of the chosen models. The design time would mostly depend on the CFD analysis for a specific configuration.

Design Variables		R (nm)	λ	x	C_f	T	t/c	h (ft)	M	AR	Λ (deg.)	S_{ref} (ft^2)
Initial Value		3378	0.25	1.0	1.0	0.5	0.05	45000	1.6	5.5	55	1000
Optimal Value	CO(S)	3990	0.12	0.99	1.18	0.127	0.08	55442	1.5	5.5	56	1047
	CSSO-RS	3235	0.4	0.84	0.99	0.208	0.081	59154	1.7	3.6	44.7	1208
	BLISS	3235	0.4	0.75	0.75	0.156	0.06	60000	1.4	2.5	70	1500
Coupling Variable		W_T (lb)	W_F (lb)	Θ	L (lb)	D (lb)	L/D	SFC	W_E (lb)	ESF		
Initial Value		41195	11254	1.0285	46231	5264	9.5	0.8818	6550	0.536		
Optimal Value	CO(S)	45207	37708	1.9927	38839	4313	5.8	0.954	7882	0.949		
	CSSO-RS	46828	16241	1.0641	46828	5332	8.783	1.1451	6739	0.530		
	BLISS	51411	7306	1.0002	51411	13478	3.814	1.1075	7058	0.556		

Table 1: Optimization results for a supersonic jet design.

What is most relevant perhaps is that the optimization techniques are being applied to disciplines beyond the traditional line of thinking where one may have considered balancing structural parameters against aerodynamic characteristics. It is providing aerodynamicists a better means to bring the combined benefits of such diverse disciplines as maintainability, variation within the design process as well as design reconfiguring, life cycle costs, fuel economy, maintenance, training, support and a whole new approach to the complete system integration processes. Advanced MDO methods and other numerical modeling techniques have also increased the ability to obtain more knowledge per cycle and the number of design cycles executable in a given time. In a recent neural network study of at IAR [4], optimization based solution were readily used in conjunction with wind tunnel testing to reduce the total number of runs required to clear the store trajectory of a missile released from a CF-18 aircraft. Figure 2 shows the predicted results of the four aerodynamic coefficients by the trained network at M = 0.95, AOA = 0^o, and AOA = -3^o and -15^o respectively. The predictions are in good agreement with the wind tunnel data for all travel paths.

Following the initial phase of shape estimates and performance definitions, the simulation team should produce suitable CFD models of the selected configurations to critically investigate the performance under all operational regimes. For performance investigation under cruise conditions with attached and/or mild separation flows on exposed surfaces, most panel methods are satisfactory. Figure 3 shows a typical example of CFD calculation for a helicopter. With sufficient expertise available in a team it would be possible to produce a good potential method based solution in a couple of days on an SGI Origin 2000 type platform with 8 CPU's. Clearly, panel methods are not expected to cope with flow complexities typically associated with landing and take off maneuvers and more demanding Euler and/or Navier Stokes based computational methods for such studies should be used.

For a more thorough understanding of viscous separating flows, one should to utilize more suitable Navier – Stokes methods. However, there is still an element of uncertainty because of the unsteadiness and interference from the rotor flow. There have been attempts made to acquire a better understanding of the rotor flow using coupling techniques, which treat the rotor as an actuated disk boundary condition in the main flow field [5]. However, this is still an empirical fixing, as the method cannot account for the instantaneous flapping or twisting of the rotor blades. A more advanced simulation would involve treating the rotor blades as separate surfaces represented individually in a Chimera block, which is housed in the outer parent grid. The flow past

each rotational setting of the Chimera block is updated in a quasi-steady fashion to obtain a better understanding of the flow. Results from one such study on ROBIN generic helicopter configuration is shown in Figure 4. A purely unsteady version of this simulation would be addressed when the rotation of the Chimera grid is automatically synchronized with the computational time step of the overall calculation. In terms of turn around times, more complex Navier-Stokes methods for steady solution may require a couple of weeks of meshing and solution. Whereas, quasi-steady or unsteady flow investigation for moving rotor equipped vehicles may require several months to obtain a satisfactory solution. CFD simulations on fixed wing aircraft are comparatively easier to perform. Given that the Navier Stokes method can be considered as most reliable predictive tools next to the actual wind tunnel measurements, panel methods can provide most of the design features during cruise conditions. A comparison of the computational effort required in producing CFD based simulations on an SGI Origin 2000 machine with 8 CPU's for a Bell 412 helicopter using panel methods and more rigorous Euler and Navier-Stokes solutions is shown in Table 2.

Method	Potential based Panel Methods	Euler equations based solution	Navier-Stokes equations based solution
Grid (PY- days)	5	6	7
Steady solution at one rotor setting	Up to 4 hours, depending on the number of panels	5 days	10 days
Complete quasi- steady solution	1 day	10 days	20 days

Table 2: Comparison of turnaround times for CFD based solution on Bell 412 helicopter.

Frequently, equipment vendors have not addressed the extended military implications, which are of primary interest for the procurement. For example, under theatre military situations, the helicopter may be required to perform under conditions for which it was never planned. It was perhaps never designed to carry the type of mission kits and pods that it is subjected to under battle conditions. Computational models do provide the expediency, convenience and accuracy of conducting such studies.

The simulation techniques become increasingly useful when one considers small variation in designs or impact of small protuberances on otherwise smooth aerodynamic designs. In fact one such study was conducted to examine the effect of tiny attachment lugs, which support a missile to a wing surface under carriage conditions. It was learnt through a CFD study that the attachment lugs have strong aerodynamic implications on the performance of the released missile. Figure 5 shows the computed flow past the missile with lugs. The lugs invoke separation effects on C_D and C_N and other aerodynamic interference beyond their size and blockage area.

As mentioned earlier, IAR is also involved with the Canadian Department of National Defence (DND) in studying safe trajectories of weapon systems ejected from a moving platform. Again as the first option one would use the quick and ready potential based methods to carry out the preliminary investigation. However, it would be necessary to carry out a comprehensive validation exercise before applying panel methods for trajectory calculations. The results from one such exercise involving the use of USAERO to calculate the drop of a store from a standard wing are shown in Figure 6. The computed results show encouraging agreement with measurements obtained from literature. The same approach was then adopted to compute the trajectory of the MK82 missile when released from the Bell412 helicopter [6]. The solution is shown in Figures 6 and 7.

For a fixed wing aircraft the approach is very similar. Figure 8 shows a typical CF-18 aircraft configured in a panel grid format. USAERO based computations were carried out to study the path of the stores as they are released from the aircraft. More rigorous studies of this concept have been performed at IAR by Fortin and Benmeddour [7], using more advanced Euler techniques. A typical JDAM store separation from CF-18 is shown in Figure 9 at 0.24s after release. The resources, time and effort required to conduct a panel method based trajectory computation is much smaller than those required for more accurate Euler and Navier-Stokes

investigations. Typically one would require a period of up to one week to construct a satisfactory panel grid followed by a few days of USAERO computations. This would be a fraction of the time, effort and computational resources required to perform a similar Euler or Navier-Stokes equations based study. The first order method may provide a good estimate of a store release trajectory, which has substantial safety margins. In situations where the miss distances are small, one would require more rigorous Navier-Stokes based analysis.

Conclusion

Simulation techniques are beginning to play an increasingly important role in assessing the performance of airborne vehicles procured by DND. Optimization techniques and other CFD methods can be used effectively for evaluating the most appropriate configurations, for given requirements.

Numerical modeling is also extremely useful for studying off-design military applications and other small variations in configuration during the in-service life of a procured vehicle. Fast panel method techniques could be very useful in quick estimates of performance under normal operations. For more challenging maneuvers involving complex surface deployments, one may have to resort to more tedious numerical techniques.

Acknowledgement

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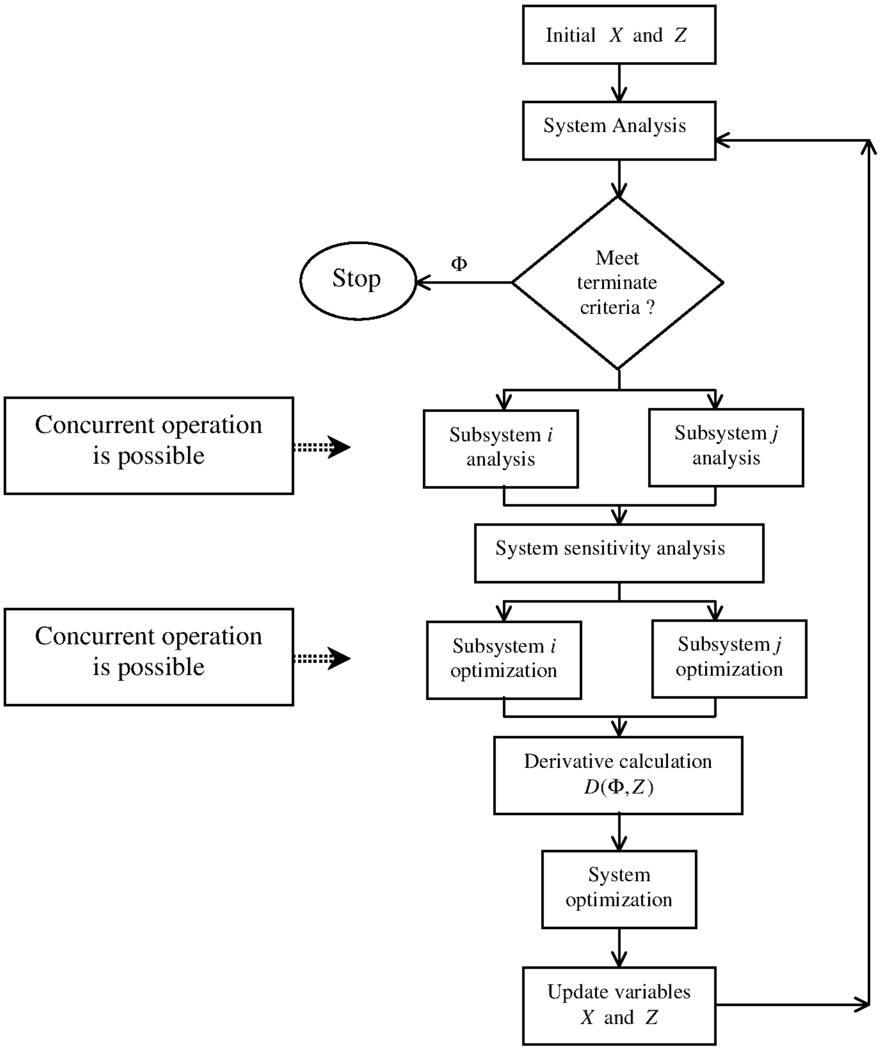

Figure 1: Flowchart of BLISS Algorithm.

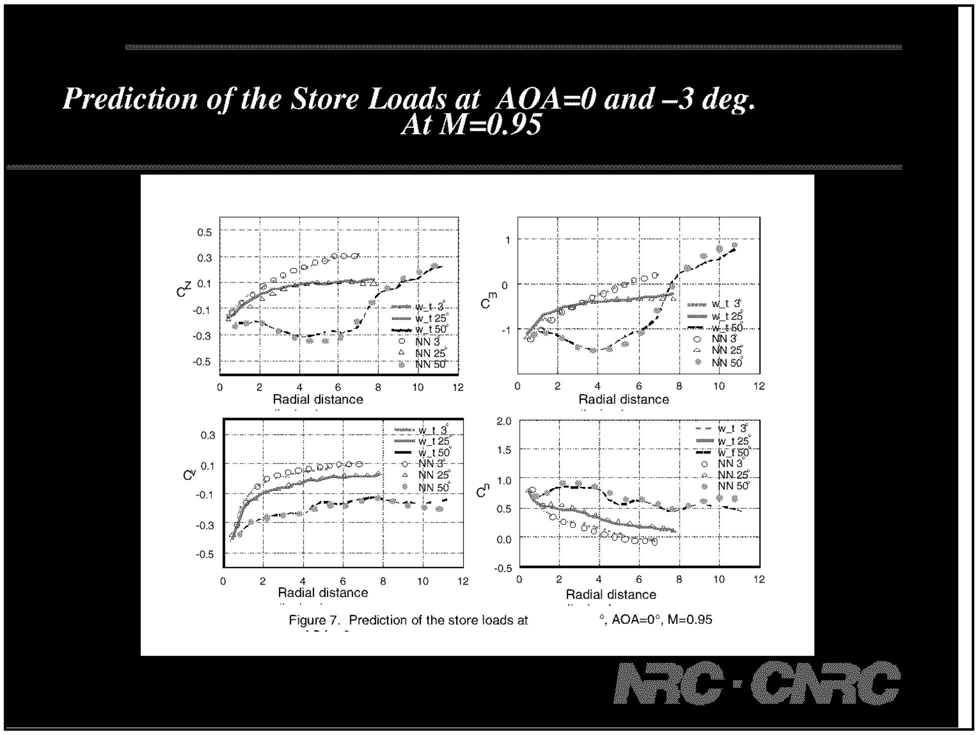

Figure 2: Predicted results of the four major aerodynamic coefficients by the trained network at M = 0.95, AOA = 0°, -3° and -15°, respectively [4].

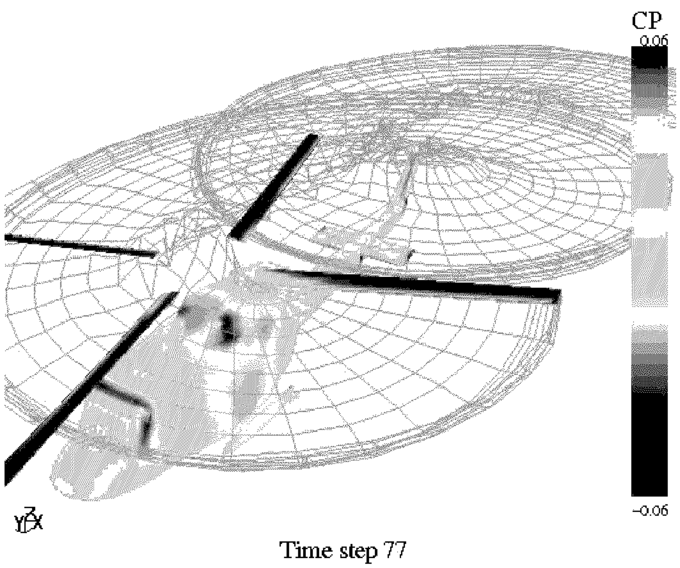

Figure 3: Typical example of CFD prediction of a helicopter flow field.

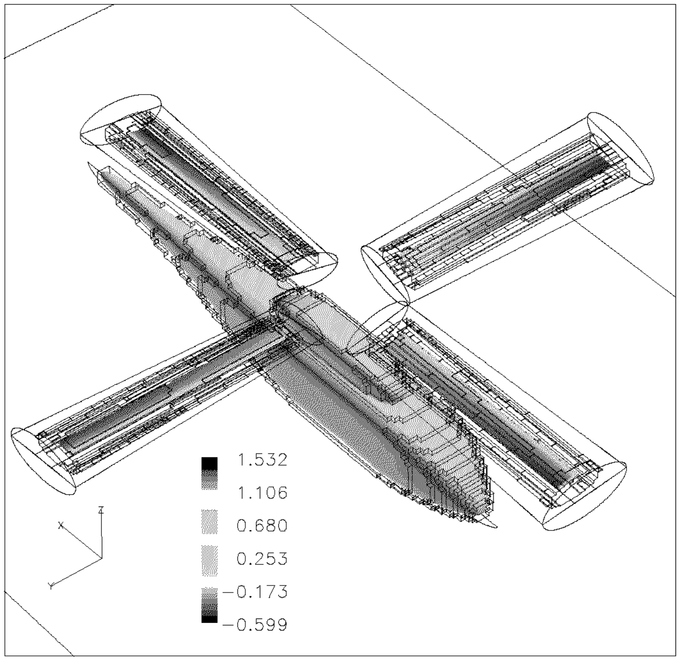

Figure 4: Robin generic helicopter configuration, meshed by Chimera grid technique.

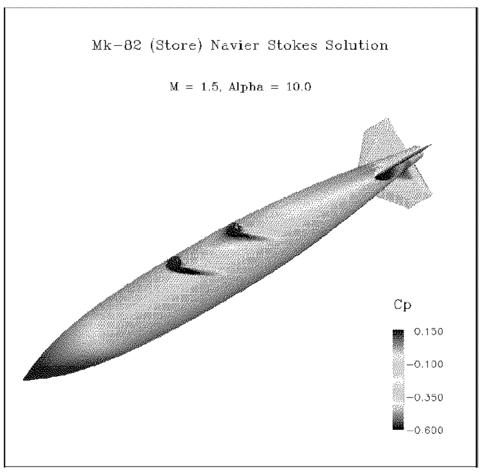

Figure 5: The aerodynamic effect of attached lugs.

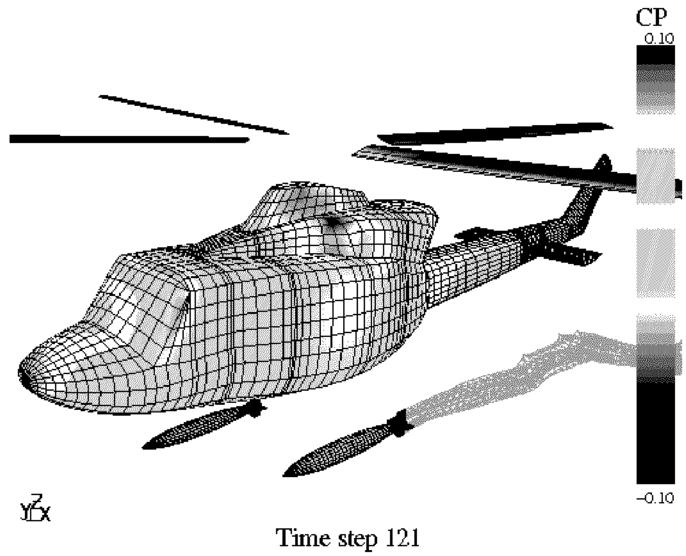

Figure 6: Panel method based modeling of MK82 missile dropped from Bell 412 helicopter.

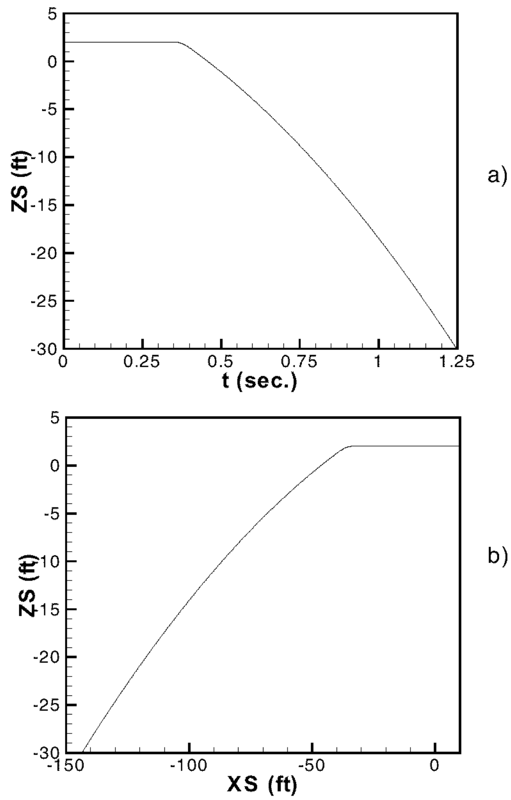

Figure 7: Store release trajectories for a calibration model.

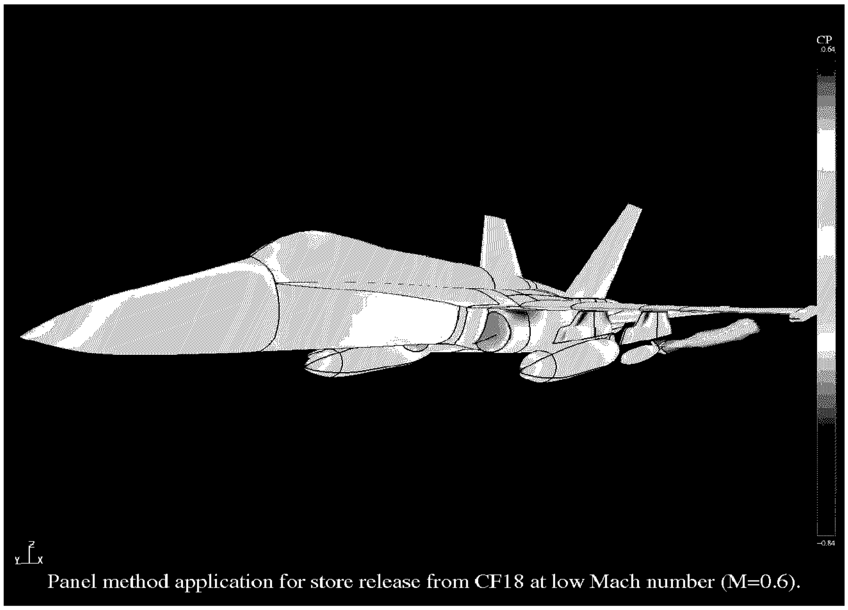

Figure 8: USAERO based computations for the flow around a typical CF-18 aircraft.

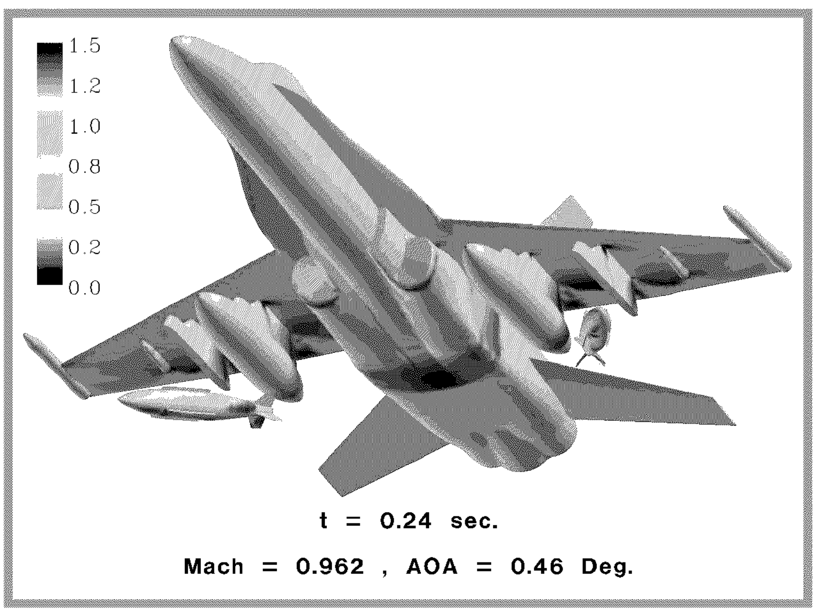

Figure 9: Store release calculations at IAR showing Mach number flow field, M_∞= 0.962, AOA = 0.46° altitude 6332 ft. , dive angle = 43° [7].